©Operative Dentistry, 2021, **46-5**, 529-536

Laboratory Research

# Effect of Deep Margin Elevation on Interfacial Gap Development of CAD/CAM Inlays after Thermomechanical Cycling

W Moon • SH Chung • J Chang

### Clinical Relevance

The margin elevation technique using RMGI can be used as an adjunct procedure to enhance interfacial adaptation of CAD/CAM lithium disilicate inlays with deep margins. The technique may be beneficial for long-term clinical services for CAD/CAM intracoronal restorations with large internal spacing.


## SUMMARY

**The aim of this study was to evaluate interfacial gap formation of CAD/CAM lithium disilicate inlay margins before and after thermomechanical loading.**

**Methods and Materials: Mesio-occlusal-distal cavities were prepared on 12 extracted mandibular molars. The gingival margin of one proximal box was elevated with resin modified glass ionomer (RMGI) by a height of 2 mm (Group E [elevation]), and the margin of the other side served as a control (Group NE [no elevation]). Lithium disilicate computer-aided design and computer-aided manufacturing (CAD/CAM) inlays were fabricated and bonded with a self-adhesive resin cement. An aging process was simulated on the specimens under thermomechanical cycling by using a chewing simulator. Marginal integration was evaluated under scanning electron miscroscopy (SEM) using epoxy resin replicas before and after cycling. Marginal areas were stained with silver nitrate solution, and the volumetric gap was measured at the bonded interfaces using micro-computed tomography (CT) before and after cycling. Statistical analyses were performed using paired *t*-tests, the Wilcoxon signed rank test, and the Mann–Whitney test ($\alpha$<0.05).**

**Results: SEM showed marginal discontinuities in Group NE that increased after thermomechanical cycling. Micro-computed tomography exhibited three-dimensional dye-penetrating patterns at the interfaces before and after cycling. Interfacial**


Wonjoon Moon, DDS, PhD candidate, Department of Dental Biomaterials Science, School of Dentistry and Dental Research Institute, Seoul National University, Seoul, Republic of Korea

Shin Hye Chung, DDS, MSD, PhD, associate professor, Department of Dental Biomaterials Science, School of Dentistry and Dental Research Institute, Seoul National University, Seoul, Republic of Korea

*Juhea Chang, DDS, MSD, PhD, clinical professor, National Dental Care Center for Persons with Special Needs, Seoul National University Dental Hospital, Republic of Korea

*Corresponding author: 101 Daehak-ro, Jongno-gu, Seoul 03080, Republic of Korea; e-mail: juhchang@snu.ac.kr

https://doi.org/10.2341/20-310-L

**disintegration was larger in Group NE before cycling ($p<0.05$). Thermomechanical cycling increased the gaps in both Groups NE and E ($p<0.05$). The gap increment from thermomechanical cycling was larger in Group NE ($p<0.05$).**

**Conclusions: Thermomechanical cycling induced interfacial disintegration at the lithium disilicate CAD/CAM inlays, with deep proximal margins. Margin elevation with RMGI placement reduced the extent of the interfacial gap formation before and after the aging simulation.**

## INTRODUCTION

With advancements in digital dentistry and adhesive techniques, computer-aided design and computer-aided manufacturing (CAD/CAM) inlays have shown favorable outcomes as a minimally invasive restorative regimen.[1] In a stress-bearing area, lithium disilicate ceramic can be the optimal choice, with its high characteristic strength among the diverse composition of CAD/CAM restorative materials.[2] Several previous studies have evaluated the mechanical properties and internal adaptation of CAD/CAM fabricated restorations, with lithium disilicate glass ceramics serving as the control groups to be compared among various polymer-infiltrated ceramics and other types of glass ceramics.[3,4] From a clinical perspective, CAD/CAM inlays of lithium disilicate glass ceramics have had a 100% survival rate for 2 years, which is also highly rated by modified criteria of the United States Public Health Service Commissioned Corps.[5]

In multiple workflows for CAD/CAM restorations that include tooth scanning, restoration designing, block milling, crystallization firing, and final finishing and polishing, each individual step can affect the quality of marginal and internal adaptation.[6] The interfacial gap formation between the restoration and tooth surfaces is inevitable, and the space is filled with luting cement that is susceptible to mechanical, physical, and thermal stresses. According to a systematic review of the marginal and internal fit of CAD/CAM inlay/onlay restorations, the values for the marginal fit largely ranged between 36 μm and 222.5 μm, and ranged between 23 μm and 406.5 μm for the internal fit.[3] When the aging process was simulated, a gap increment was prevalent regardless of the variation in experimental settings. Particularly, when inlay restorations include extended mesio-occlusal-distal (MOD) cavities, the margins of deep proximal boxes are not surrounded by enamel for durable bonding. Moreover, deep proximal boxes of CAD/CAM inlays complicate the clinical steps throughout cavity preparation, optical scanning, margin readings, adhesive cementation, finishing, and polishing. Therefore, a deep margin elevation technique can be considered to position the margins to a more manageable, supragingival level by applying base materials in the bottom of proximal boxes.[7] However, a literature review on deep margin elevation in indirect adhesive restorations revealed conflicting results, and studies included in the review had mainly applied conventional measurements for marginal adaptation by scanning electron microscopy (SEM) using epoxy replicas.[8] Further, limitations exist for percentile measurement of continuous margins on the restoration surfaces in a two-dimensional (2D) plane.

Inlays have a more complex geometry than full-coverage crowns and provide interfacial clearance sufficient for internal adjustment.[3] A CAD/CAM workflow that incorporates multiple digitalized steps tends to accumulate interfacial spacing that results in both marginal and internal gap increments at the final step. Recently, three-dimensional (3D) measurements using micro-computed tomography (micro-CT) has been advocated as a useful tool to evaluate numerous points of the interfacial areas between restoration and tooth surfaces. Using micro-CT, multiple sectional images can be constructed, and virtual cement spaces under inlays can be measured for quantitative analysis.[9] Moreover, an unaltered observation setting enables timewise observation to confirm the interfacial disintegration induced by the aging simulation.[10]

The purposes of this study were (1) to determine 2D and 3D gap formation using SEM and micro-CT, (2) to compare the interfacial gap formation in the CAD/CAM lithium disilicate MOD inlays with and without margin elevation, and (3) to evaluate the interfacial gap increment after thermomechanical loading. The null hypothesis was that the margin elevation of CAD/CAM MOD inlays with RMGI would not affect interfacial gap formation before and after thermomechanical cycling.

## METHODS AND MATERIALS

### Specimen Preparation

Twelve freshly extracted mandibular molars were used to prepare MOD cavities (4 mm in bucco-lingual width, 3 mm in occlusal depth, and 4 mm in axial depth of the proximal box). All gingival margins of proximal boxes were located beneath the cementoenamel junction. Either a mesial or distal proximal box was randomly selected (Group E [elevation]), and its gingival margin was elevated by 2 mm by layering RMGI cement (Fuji II LC; GC, Tokyo, Japan). The gingival margin at the other side (Group NE [no elevation]) was not elevated (Figure 1). The proximal cavities were cleansed with polyacrylic acid (dentin conditioner; GC, Tokyo, Japan) and layered with a RMGI cement. After placement of the RMGI cement, the cavity forms were finished with fine diamond burs (Komet Inlay-Preparation Set 4261; Gebr. Brasseler GmbH & Co. KG, Lemgo, Germany). Specimens were embedded in an epoxy resin (Cold Mounting Systems Epoxy Systems; Metallurgical Supplies, Buffalo, NY, USA) that exposed the coronal portion of the teeth. Each cavity was scanned using CEREC Omnicam (Dentsply Sirona, Hanau-Wolfgang, Germany) and an MOD inlay was designed with the cement space set by 150 μm. A lithium disilicate CAD block (MAZIC Claro CAD, Vericom, Chuncheon, Korea) was milled using a milling machine (CEREC MC XL; Dentsply Sirona) and went through crystallization in a firing furnace (Multimat Cube; Dentsply Sirona). The inlay specimens were then etched with a 4% hydrofluoric acid (Porcelain Etchant; Bisco, Schaumburg, IL, USA), treated with a primer (Porcelain Primer; Bisco), and bonded with a resin cement (RelyX U200; 3M Oral Care, St. Paul, MN, USA). The cemented specimens were stored in 37°C water for 24 hours.

## Thermomechanical cycling

All specimens underwent thermomechanical aging simulation that consisted of 1,000,000 cycles of mechanical loading and 8,836 cycles of thermal alterations (40 seconds at 5°C and 55°C, respectively) in a chewing simulator (Chewing Simulator CS-4; SD Mechatronik, Feldkirchen-Westerham, Germany). The load was applied at the central fossa with a 1-mm round-ended cylindrical steel tip. The loaded weight was chosen as 5 kg, equivalent to an effective loading force of 49 N.[11]

## Two-dimensional Interfacial Analysis Using SEM

Before and after thermomechanical cycling, silicone impressions of the mesial and distal margins of all specimens were taken with putty (Exafine Putty Type; GC) and light-body impression materials (Examixfine; GC) to observe 2D marginal integration. Based on the impression, epoxy models were fabricated to be observed under a field emission SEM (FE-SEM JSM-7401F; JEOL, Tokyo, Japan) at 100x magnification. Along the gingival margin of the proximal box, the percentage of marginal discontinuity was calculated using ImageJ software (ImageJ; NIH, Bethesda, MD, USA). The same measurement was repeated on all specimens after thermomechanical cycling.

## Three-dimensional Interfacial Analysis Using Micro-CT

After silicone impressions were taken, the specimens were immersed in a radiopaque dye, 50% w/w silver nitrate ($AgNO_3$) solution (pH = 8.48), for 6 hours in the dark at room temperature. Specimens were scanned using a micro-CT scanner (Skyscan 1172; Bruker, Kontich, Belgium). The scanning parameters were 100kV and 100μA using an aluminum and copper filter, with an exposure time of 1,180 ms. The pixel size was 8.85 μm, with a rotation of 0.40 and an average frame of 3. 3D images were acquired by 3D reconstruction (NRecon; Bruker), 3D modeling (CTAn; Bruker), and 3D analysis (CTVol; Bruker). To detect and confirm the presence of silver nitrate, the dye solution was scanned under the same condition. Then, standard parameters and thresholds for silver nitrate were determined and the volume of dye penetration was calculated for summation. For the volumetric calculation, sagittal images were obtained from the surface of the proximal

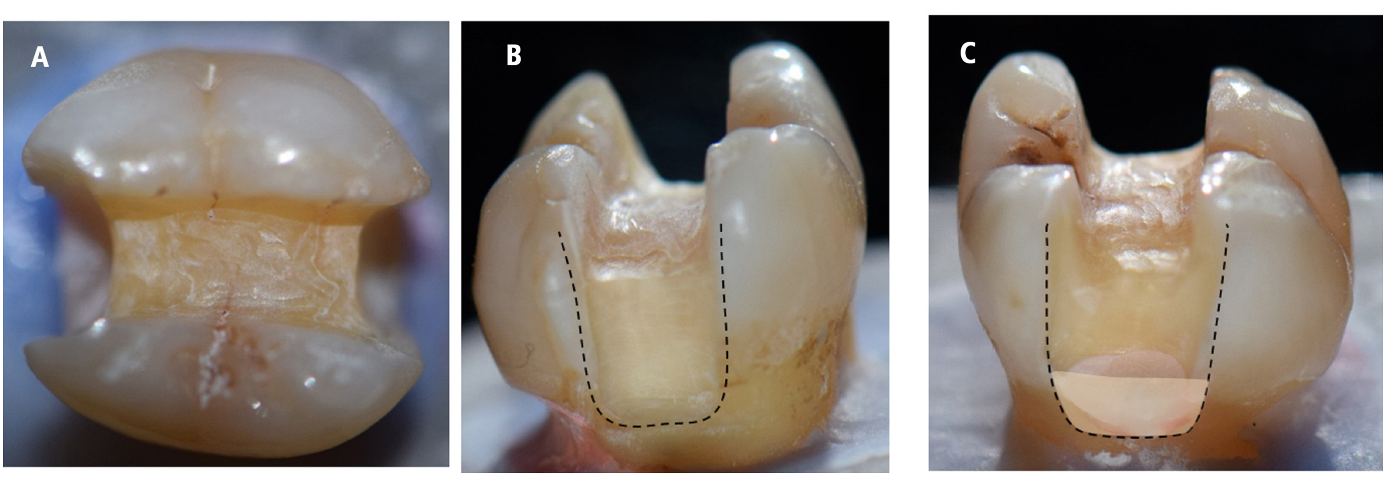


Figure 1. *(A): Tooth specimen with a mesio-occlusal-distal inlay cavity. A proximal box without margin elevation (B) and with margin elevation by resin modified glass ionomer layering (C).*

box to the axial wall. Additionally, cross-sectional images were obtained to analyze the interfaces between dentin and inlay in Group NE, and those between RMGI and inlay in Group E. The above procedures were repeated after thermomechanical cycling, and the corresponding interfacial configuration was analyzed in the same manner.[12]

### Statistical Analysis

The volume of silver nitrate penetration was analyzed as follows. Data from before and after thermomechanical cycling was compared using the Wilcoxon signed rank test and paired *t*-tests based on the normality tests. To compare Groups E and NE, the Mann–Whitney U test was used, as the data did not follow the normal distribution. SPSS Statistics for Windows (version 26.0; IBM, Armonk, NY, USA) was used with the significance level set at $\alpha<0.05$. The sample size was determined based on previous studies that reported the means and standard deviation (SD) for the interfacial gap volumes of MOD inlays evaluated by micro-CT.[10,13]

## RESULTS

Based on the SEM evaluation before and after thermomechanical cycling, percentile marginal discontinuities were observed in 12 specimens in each group (Figure 2). Before thermomechanical cycling, 6 specimens showed marginal discontinuity (mean [SD] = 30.3 [40.8] %) in Group NE, while all margins were intact in Group E. After cycling, discontinuity increased in Group NE (mean [SD]=39.5 [42.0] %) and all margins stayed intact in Group E.

Micro-CT analysis before and after thermomechanical cycling determined the volumes of interfacial dye penetration (Figure 3). Proximal boxes with margin elevation revealed significantly less interfacial gap volume compared with those without margin elevation (Table 1; Figure 3A, $p<0.05$). After cycling, the volumetric gap increased in both groups, but the increment was less in Group E (Figure 3B, $p<0.05$). The reconstructed images of the dye-penetrated interfaces exhibited a lesser degree of penetration in Group E (Figure 4). The penetration was extended in both groups after cycling.

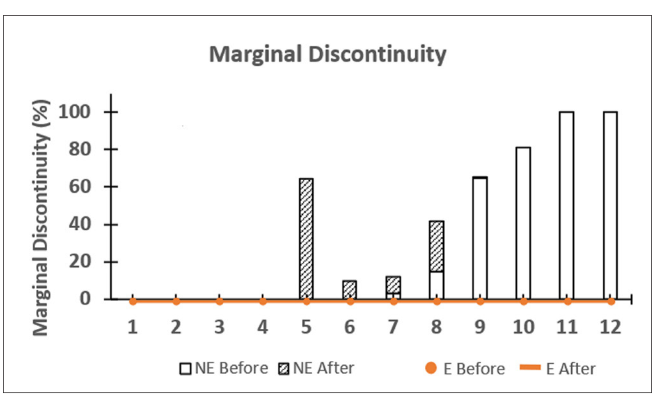


Figure 2. *Marginal discontinuity (%) at the gingival margins with and without elevation determined before and after thermomechanical cycling. Abbreviations: E, elevation; NE, no elevation.*

Figure 5 shows the cross-sectional images of micro-CT taken at the interfaces for evaluation. The white images represent the presence of silver nitrate at the interface between the inlay and the deep gingival floor in Group NE and between the inlay and RMGI base in Group E. Before cycling, the interfaces exhibited minimal penetration of silver nitrate. After cycling, the presence of dye was slightly increased at the marginal surfaces in both groups but was not noticeably extended into the internal areas.

## DISCUSSION

This study evaluated the interfacial gap developed under CAD/CAM MOD inlays made of lithium disilicate ceramic to determine the effect of deep margin elevation, and to also evaluate the impact of thermomechanical cycling on gap formation. The 3D analysis using micro-CT showed that the margin elevation using RMGI lessened the interfacial gap at the deep gingival margins and reduced the gap increment under thermomechanical cycling. Therefore, the null hypothesis that margin elevation with RMGI would not affect interfacial gap formation before and after thermocycling was rejected.

The margin elevation technique is a direct adhesive restoration that functions as a base under an indirect restoration to enhance the marginal adaptation at deep margin areas.[14] It came from the open sandwich

Table 1: *Volumetric Measurement of Interfacial Gap Formation Determined by Micro-CT Evaluation*

| Groups | Interfacial Gap Volume ($mm^3$) Mean (SD) | | *p*-values |
|---|---|---|---|
| | Before Cycling | After Cycling | |
| Group NE (No elevation) | 0.098 (0.097) | 0.178 (0.165) | 0.002[a] |
| Group E (Elevation) | 0.021 (0.025) | 0.054 (0.053) | 0.003[b] |
| *p*-values | 0.007[c] | 0.017[c] | |

*Abbreviation: SD, standard deviation.*
[a] *Wilcoxon signed rank test.*
[b] *Paired* t*-test.*
[c] *Mann-Whitney test.*

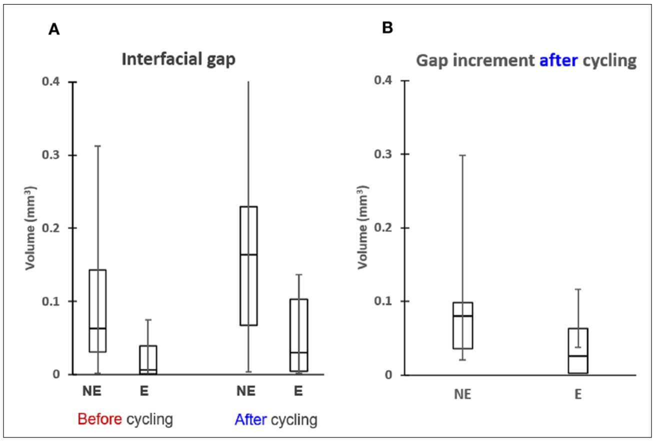


Figure 3. *Volumetric measurement of interfacial gap formation determined by micro-computed tomography evaluation. Abbreviations: E, elevation; NE, no elevation.*

technique that places base material at the bottom of open proximal boxes to reduce polymerization shrinkage of overlying composite resins.[15] Among various adhesive restorative materials, RMGI was shown to be an optimal material for this purpose, benefited by not only the chemical adhesion to deep dentin and hygroscopic expansion in the humid oral environment, but also by mechanical and adhesive properties enhanced with resin-based components. Composite resins are an alternative option that exhibit satisfying results, particularly for CAD/CAM glass-ceramic restorations with high strength and large interfacial spacing.[15,16] However, in clinical circumstances, clean and sound dentin surfaces are difficult to obtain for optimal bonding in the deep marginal areas. Moreover, teeth with deep proximal defects often involve caries-affected dentin that has an inferior capability for hybridization in its tubular structures.[17] Alternately, application of RMGI at the deep proximal margin can be less affected by contamination issues in suboptimal operating conditions and is not as technique-sensitive to practitioners as composite resins are.[18] The proximal boxes with margin elevation using RMGI contained two different interfaces: one between the inlay and the RMGI base, and the other between the RMGI base and the deep dentinal floor. In our observations using SEM, both interfaces were intact before and after thermomechanical cycling. Micro-CT evaluation showed that the marginal and internal gaps were hardly detected at the interface between RMGI and dentin, while gaps were evident at the interface between RMGI and resin cement. So, the latter was selected for our measurement and analysis. We considered the chemical bonding between RMGI and dentin was relatively well maintained, and spatial compensation resulted from water resorption and hygroscopic expansion of RMGI, largely due to hydrophilic monomer components such as hydroxyethyl methacrylate.[19] This aspect seemed to contribute to diminishing the space between RMGI and resin cement, resulting in less space than that between dentin and resin cement.

A CAD/CAM fabrication system incorporates many digitized processes that are influenced by cavity

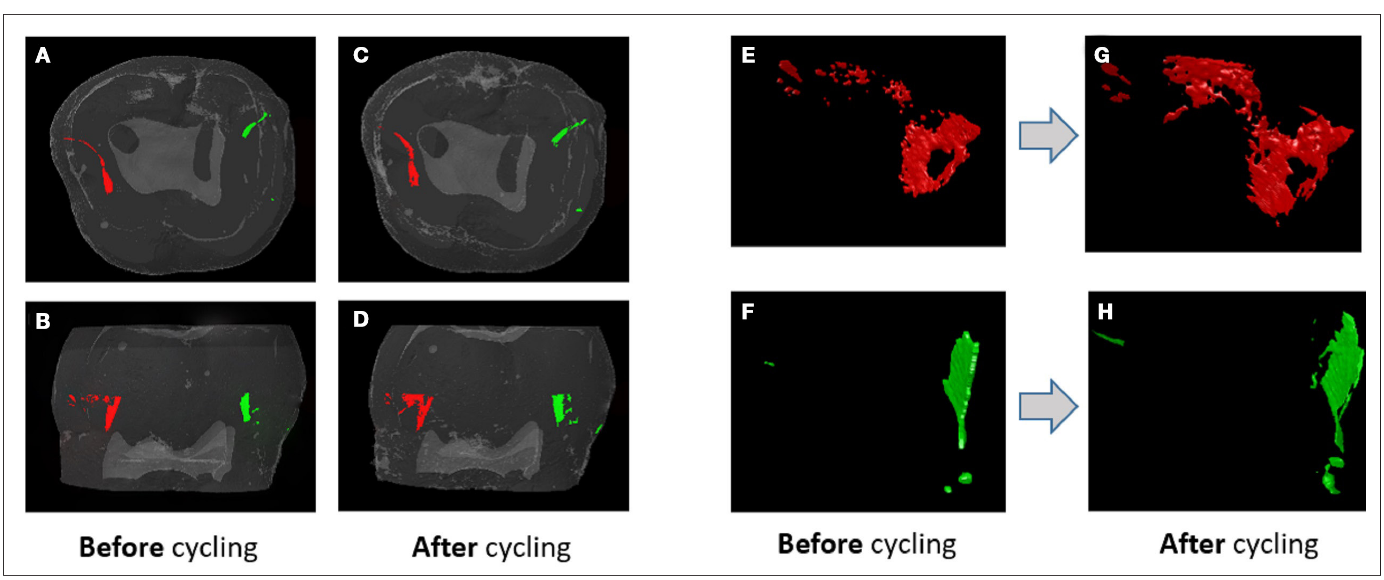


Figure 4. *Occlusal (A, C) and lateral views (B, D) of dye penetrating modes of a single representative specimen from three-dimensional reconstruction and modeling of micro-computed tomography data. The boxes showing margin elevation (red) shows a larger extent of dye penetration at the interfaces compared with that of the boxes showing margin elevation (green). Images before (A, B) and after (C, D) thermomechanical cycling showed an increase in the interfacial gap after cycling. Magnified views of dye penetration before (E, F) and after (G, H) thermomechanical cycling.*

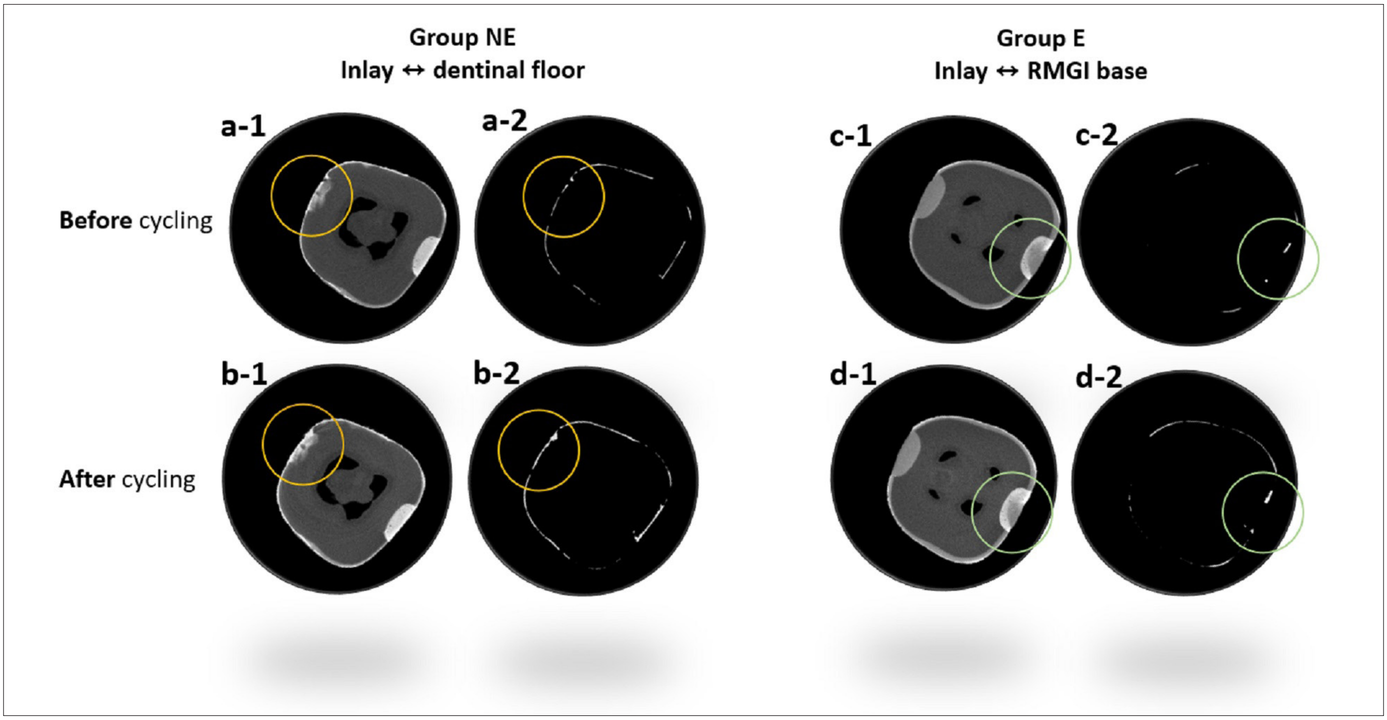


Figure 5. *Micro-computed tomography images indicating dye penetration at both proximal boxes of the same specimen. Circled images show the dye-penetrated interfaces between inlay and dentinal floor (Group NE) and between inlay and RMGI base (Group E). Paired images show the whole specimen (a-1, b-1, c-1, d-1) and the dye penetrants with surrounding substrates filtered out (a-2, b-2, c-2, d-2). In Group NE, almost no penetration was seen at the interface between the inlay and dentinal floor (a-1, a-2), which was minimally increased after cycling (b-1, b-2). In Group E, the presence of silver nitrate was not detectable at the interface between the inlay and the RMGI base (c-1, c-2), and it was not penetrated after cycling (d-1, d-2). Abbreviations: E, elevation; NE, no elevation; RMGI, resin modified glass ionomer.*

preparation, optical impression, design algorithms, material types, milling tools, and milling machines.[20] When an optical impression is directly captured from the mouth, it is especially difficult to detect deep proximal margins.[21] Also, caries-affected tooth surfaces are often plaque retention areas prone to gingival bleeding that induce marginal contamination. Consequently, marginal inaccuracy can affect the internal fit of restorations and increase the overall cement spaces. In addition, high strength ceramics such as lithium disilicate are more sustainable in stress-bearing posterior dentition, but they have lower machinability compared with variants of polymer-based glass ceramic blocks.[3] For ease of insertion into the complex geometry of inlay preparation, sufficient clearance needs to be provided under the restoration. Altogether, inherently large interfacial spaces are gained and filled with luting cement that adjoins heterogeneous substrates with superior strength (enamel, dentin, and ceramics). Clinically, the main failures reported in class II ceramic inlays are bulk fractures rather than marginal fractures.[16] Within a thick cement layer, macro- and micro-level defects are easily created that initiate crack propagation, dislodge the inlays, and eventually lead to early failure modes.[22] The prefracture stage of internal defects is hardly detectable because it occurs in the unseen part of the restoration. Therefore, observation of marginal leakage is not a viable measure to predict restoration failures, especially when visible margins are tightly bound to sound tooth structures. As shown in Figure 5, adhesive interfaces at the tooth surfaces, which were the observation points in conventional leakage tests, were minimally affected even after aging simulation. Instead, gap development mostly occurred deep inside the cavities (Figure 4).

In previous micro-CT studies of the marginal and internal adaptation of CAD/CAM intracoronal restorations, the gap values equivalent to cement thickness was used as the outcome measures for experimental variables.[3,9,10,14,23] We focused on spatial defects that were initially produced and gradually progressed not only at the adhesive interfaces but also within the cement layer. So, silver nitrate dye was selected to distinguish the penetrant occupied spaces within a multigray-scaled component because current resin luting cements are variously comprised of monomers and fillers of dissimilar radiopacities. We evaluated silver nitrate penetration into all vacancies that represented the structural defects potentiating fatigue-based failures. The quantitative comparisons using 3D reconstruction of selected images clearly showed the changes induced from thermal and mechanical impacts.

As in other studies evaluating the efficacy of the margin elevation of CAD/CAM MOD inlays, we prepared standardized sizes of MOD cavities. Although the natural human molars used in this study provided the highest clinical relevance among other alternatives, the anatomical configuration of the remaining tooth structures and histophysiology of dentin substrates differed among specimens, which was attributed to a large variation of the outcome values. Moreover, as demonstrated in a study comparing the internal fit between pressed versus milled ceramic inlays,[22] CAD/CAM inlays are vulnerable to imperfect preparation geometry and provide larger compensating clearance in the interfaces through milling processes. The interfacial gap may be more accentuated in a long and narrow configuration such as deep proximal boxes. Our study also showed that Group NE revealed larger gap values with higher variances than Group E. Considering interspecimen variabilities, we performed paired tests to compare both proximal boxes within the same specimen, and simplified parameters were put into the analyses (margin elevation versus none, and before versus after cycling). Additional approaches would be needed to improve the current experimental settings. For instance, an increase in sample size would make it possible to incorporate more variables to determine the optimal clinical technique to minimize interfacial disintegration of CAD/CAM ceramic inlays. Also, 3D printing of tooth models may enable researchers to standardize experimental protocols for consideration in future studies.

## CONCLUSION

Based on the results of this study, deep margin elevation with RMGI can be an adjunct technique to decrease interfacial gap formation in CAD/CAM lithium disilicate inlays. Margin elevation decreased the initial gap formation and reduced the gap increment after thermomechanical cycling. The interfacial disintegration mainly occurred in the deep areas of proximal cavities, while surface margins remained integrated through the aging processes.

### Acknowledgement

This work was supported by Creative-Pioneering Researchers Program through Seoul National University(SNU).

### Conflict of Interest

The authors of this manuscript certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

*(Accepted 20 March 2021)*

## REFERENCES

1. Spitznagel FA, Scholz KJ, Strub JR, Vach K, & Gierthmuehlen PC (2018) Polymer-infiltrated ceramic CAD/CAM inlays and partial coverage restorations: 3-year results of a prospective clinical study over 5 years *Clinical Oral Investigations* **22(5)** 1973-1983.

2. Spitznagel FA, Boldt J, & Gierthmuehlen PC (2018) CAD/CAM ceramic restorative materials for natural teeth *Journal of Dental Research* **97(10)** 1082-1091.

3. Goujat A, Abouelleil H, Colon P, Jeannin C, Pradelle N, Seux D, & Grosgogeat B (2018) Mechanical properties and internal fit of 4 CAD-CAM block materials *Journal of Prosthetic Dentistry* **119(3)** 384-389.

4. Goujat A, Abouelleil H, Colon P, Jeannin C, Pradelle N, Seux D, & Grosgogeat B (2019) Marginal and internal fit of CAD-CAM inlay/onlay restorations: a systematic review of in vitro studies *Journal of Prosthetic Dentistry* **21(4)** 590-597.e3.

5. Coşkun E, Aslan YU, & Özkan YK (2020) Evaluation of two different CAD-CAM inlay-onlays in a split-mouth study: 2-year clinical follow-up *Journal of Esthetic and Restorative Dentistry* **32(2)** 244-250.

6. Duqum IS, Brenes C, Mendonca G, Carneiro TAPN, & Cooper LF (2019) Marginal fit evaluation of CAD/CAM all ceramic crowns obtained by two digital workflows: an in vitro study using micro-CT technology *Journal of Prosthodontics* **28(9)** 1037-1043.

7. Magne P & Spreafico RC (2012) Deep margin elevation: a paradigm shift *American Journal of Esthetic Dentistry* **2(2)** 86-96.

8. Juloski J, Köken S, & Ferrari M (2018) Cervical margin relocation in indirect adhesive restorations: a literature review *Journal of Prosthodontic Research* **62(3)** 273-280.

9. Uzgur R, Ercan E, Uzgur Z, Colak H, Yalcin M, & Ozcan M (2018) Cement thickness of inlay restorations made of lithium disilicate, polymer-infiltrated ceramic and nano-ceramic CAD/CAM materials evaluated using 3D x-ray micro-computed tomography *Journal of Prosthodontics* **27(5)** 456-460.

10. Ashy LM, Marghalani H, & Silikas N (2020) In vitro evaluation of marginal and internal adaptations of ceramic inlay restorations associated with immediate vs delayed dentin sealing techniques *International Journal of Prosthodontics* **33(1)** 48-55.

11. Ho TK, Satterthwaite JD, & Silikas N (2018) The effect of chewing simulation on surface roughness of resin composite when opposed by zirconia ceramic and lithium disilicate ceramic *Dental Materials* **34(2)** e15-e24.

12. Carrera CA, Lan C, Escobar-Sanabria D, Li Y, Rudney J, Aparicio C, & Fok A (2015) The use of micro-CT with image segmentation to quantify leakage in dental restorations *Dental Materials* **31(4)** 382-390.

13. Zavattini A, Mancini M, Higginson J, Foschi F, Pasquantonio G, & Mangani F (2018) Micro-computed tomography evaluation of microleakage of Class II composite restorations: an in vitro study *European Journal of Dentistry* **12(3)** 369-374.

14. Grubbs TD, Vargas M, Kolker J, & Teixeira EC (2020) Efficacy of direct restorative materials in proximal box elevation on the margin quality and fracture resistance of molars restored with CAD/CAM onlays *Operative Dentistry* **45(1)** 52-61.

15. Zaruba M, Göhring TN, Wegehaupt FJ, & Attin T (2013) Influence of a proximal margin elevation technique on marginal adaptation of ceramic inlays *Acta Odontologica Scandinavica* **71(2)** 317-324.

16. Frankenberger R, Hehn J, Hajtó J, Kramer N, Naumann M, Koch A, & Roggendorf M (2013) Effect of proximal box elevation with resin composite on marginal quality of ceramic inlays in vitro *Clinical Oral Investigations* **17(1)** 177-183.

17. Perdigão J (2010) Dentin bonding-variables related to the clinical situation and the substrate treatment *Dental Materials* **26(2)** e24-e37.

18. Farmer SN, Ludlow SW, Donaldson ME, Tantbirojn D, & Versluis A (2014) Microleakage of composite and two types of glass ionomer restorations with saliva contamination at different steps *Pediatric Dentistry* **36(1)** 14-17.

19. Dursun E, Nguyen JF, Tang ML, Attal JP, & Sadoun M (2016) HEMA release and degree of conversion from a resin-modified glass ionomer cement after various delays of light activation *Dental Materials* **32(5)** 640-645.

20. Boitelle P, Mawussi B, Tapie L, & Fromentin O (2014) A systematic review of CAD/CAM fit restoration evaluations *Journal of Oral Rehabilitation* **41(11)** 853-874.

21. Mangano F, Gandolfi A, Luongo G, & Logozzo S (2017) Intraoral scanners in dentistry: a review of the current literature *BMC Oral Health* **17(1)** 149.

22. Guess PC, Vagkopoulou T, Zhang Y, Wolkewitz M, & Strub JR (2014) Marginal and internal fit of heat pressed versus CAD/CAM fabricated all-ceramic onlays after exposure to thermo-mechanical fatigue *Journal of Dentistry* **42(2)** 199-209.

23. Alajaji NK, Bardwell D, Finkelman M, & Ali A (2017) Micro-CT Evaluation of ceramic inlays: comparison of the marginal and internal fit of five and three axis CAM systems with a heat press technique *Journal of Esthetic and Restorative Dentistry* **29(1)** 49-58.